Advanced Matching Techniques for High Precision Surface and Terrain Models

EBERHARD GÜLCH, Stuttgart

ABSTRACT

Image matching is currently gaining increased interest in the photogrammetric community to provide accurate and very dense point clouds for Digital Elevelvation Models (DEMs). Besides the traditional Digital Terrain Models (DTMs) the focus is more and more on Digital Surface Models (DSMs). It can be seen as an alternative technique or even competition to airboren laserscanning (LIDAR) which is since the last decade dominating the extraction of DEMs. The increasing application of digital filmless cameras with high radiometric resolution, increased number of images and low ground sampling distances is nowadays exploited by image matching software by different vendors.

This paper presents results of two investigations with the new MATCH-T DSM 5.2 version of inpho GmbH. The first investigation deals with automatic image matching in the difficult terrain of open pit mining including change detection and volume calculations using six sequential flights. The results show, that a very high level of automation can be reached by using filmless digital cameras and the features of the new MATCH-T DSM software. The DEMs are generated completely automatically without collection of morphological data. The results are accurate enough for this application as compared to the standard workflow with human operator stereo measurements. The automatic volume determination of cutting and filling shows in average only 0.2-1.0% difference to the manually derived volumes. A second investigation evaluates the software Building Generator of inpho GmbH to perform 3D building extraction using given 2D ground plans of buildings and MATCH-T DSM point clouds. Extensive empirical investigations of parameter settings in urban areas of different complexity and density show, that there are only few decisive parameter settings needed to yield promising results. In areas with simple to moderate complexity building types that are Rectange shaped, L-shaped, U-shaped or T-shaped can be reconstructed in LoD 2 (Level-of-Detail) with up to more than 95% success rate. If the extraction in LoD 2 fails, a LoD 1 building model is derived. The success rates using LIDAR point clouds can be almost reached also by using dense image matching point clouds. In case of complex buildings and high density of buildings the success rates are lower with strong dependency on a subdivision of the given 2D ground plans, which is also the case in LIDAR point clouds.

1. INTRODUCTION

In the last years increasing interest in DSM generation from image matching can be observed. This is not only visible in software products by several photogrammetric vendors like inpho GmbH, but also by international and national organizations which carry on investigations on the potential of automated image matching as competition or complimentary information to airborne laserscanning (LIDAR). In Haala and Wolf (2009) investigations on automated DEM (Digital Elevation Model) generation from digital aerial imagery as part of a DGPF (German Society for Photogrammetry Remote Sensing and Geoinformation) project are presented. The software MATCH-T DSM (Lemaire, 2008) was applied to high resolution digital imagery. The performance in an industrial, a residential and an agricultural area is higher than using scanned film based imagery. The quality at check points indicates the potential to reach the quality level obtained by LIDAR data.

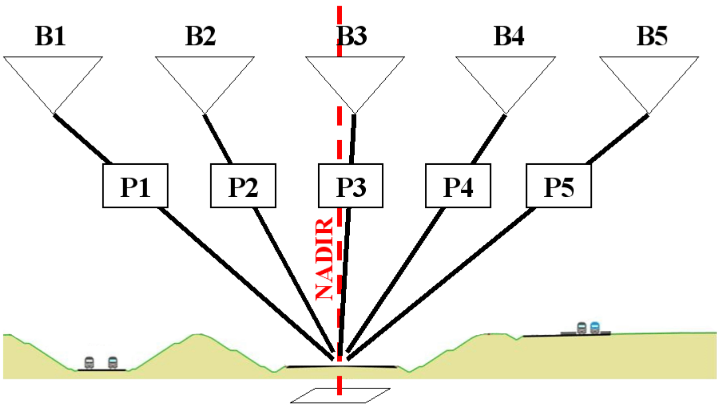
In this paper we will present two basic investigations performed at HFT Stuttgart on the quality of DEM generation using the newest MATCH-T DSM 5.2 (Beta) version of inpho GmbH (Inpho, 2009) as described in section 2. The first investigation concentrates on the difficult area of open pit mining with low texture areas, steep slopes and shadows (section 3) including an attempt for change detection to derive automatic volume determination (section 4) to eventually replace tedious manual DEM measurements. The second investigation (section 5) is focusing on the application of building extraction using dense point clouds from image matching. So far basically classical stereo measurements have been used to derive 3D building models; a tedious and cumbersome work. Some semi-automatic approaches were developed for very high level of detail (Gülch et al., 2004), but did not either allow for dramatic cutting of costs. Image matching and LIDAR can provide high quality point clouds, but unfortunately not directly the vectors for building models either. With the Building Generator by inpho GmbH a commercial software is available to derive LoD (Level of Detail) 1 and LoD 2 for 3D building models as defined by the OGC City GML standard.

2. MATCH-T DSM

In contrast to earlier versions of MATCH-T the MATCH-T DSM 5.1 and higher modules derive an extremely large number of irregular distributed surface points (Lemaire 2008, Lothammer, 2008). Out of this point cloud a grid based DTM and a grid based DSM of very high density are generated using robust filtering methods. The software allows access to all three surface representations. By leaving the stereo-model as the basic unit of earlier versions, the unit for matching is now the so called computation unit in object space.

2.1. Model selection

The MATCH-T DSM software chooses the best suited image pairs for one computation or matching unit based on two criteria: the angle of incidence and the model area (cf. Fig. 1). Image pairs are selected that have the best viewing angle of the matching unit. The number of image pair combinations increases dramatically with highly overlapping aerial images and can thus be set to a maximum (eg. 20) to limit the computational effort. One significant parameter involved is the azimuth direction. The point extraction itself is done in six major directions. If one combination does not deliver sufficient 3D points, the next best suited model for this azimuth is selected. An analysis of the number of extracted 3D points in one matching unit allows identifying poorly textured areas and thus initializes an increase of the used number of model combinations for this unit to gain as much as possible information.



a)

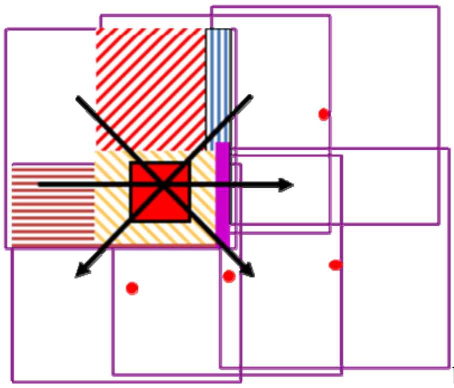
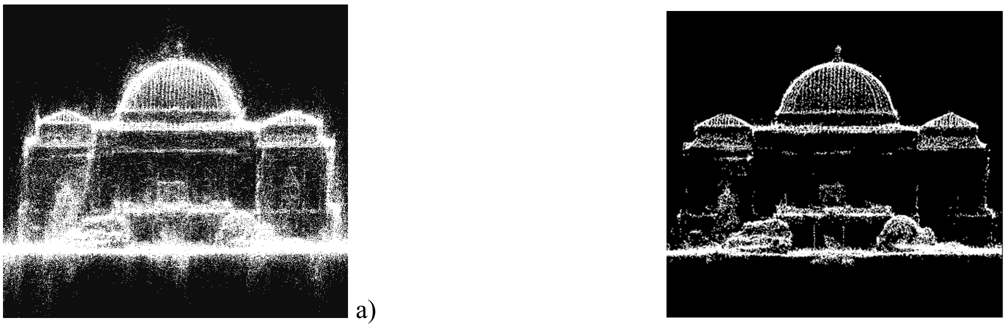

b)

Fig. 1: Criteria for selection of image pairs. a) Angle of incidence. b) Model area (Lothhammer, 2008).

2.2. Robust filtering

A second important aspect is the true 3D filtering applied in MATCH-T DSM which is an essential pre-requisite for successful DSM generation, due to the 3D nature of built-up areas in contrast to the popular finite element interpolation methods used for filtering of point clouds in classical DTM generation. The combined point clouds of all image pairs usually contain noise and gross matching errors (Fig. 2a). The elimination of gross errors in the matched point clouds is based on robust filtering. Points with high redundancy are recognized by statistical analysis and the points with the highest accuracy are selected. The filtering applied works in full 3D and is in addition used to perform data reduction without essential information loss, as shown in Fig. 2b.



a) b)

Fig. 2: 3D Filtering. a) Raw point cloud. b) Point cloud after robust 3D filtering (Lothhammer, 2008).

2.3. Parameter settings

Two general matching strategies are available: the derivation of a Digital Terrain Model (DTM) and of a Digital Surface Model (DSM). Depending on this selection the software applies different filtering methods and point densities. The DSM produces higher point densities, the DTM filters out single trees and buildings. Each strategy is further sub-divided according to terrain type and density of features. The basic parameter settings are predefined according to Table 1. The 'customized' selection allows user defined settings of the parameters. The feature density can be set from dense to very sparse.

Table 1: Parameter sets for MATCH-T DSM.

	DTM	DSM
Terrain type	dTm_flat dTm_undulating dTm_mountainous dTm_extreme dTm_customized	dSm_flat dSm_undulating dSm_mountainous dSm_extreme dSm_customized
Feature density	Dense, medium, sparse, very sparse	

2.4. Discussion

The MATCH-T DSM software makes use of several of the essential new features which digital cameras offer: the high radiometric resolution, the clear tendency in current flights for a higher forward overlap and higher side lap, and the low values for GSD (ground sampling distance).
Lothhammer, 2008 gives the following recommendations for DSM generation:

- calibrated digital camera,
- at least 60/60 overlap, and
- at least 20 cm GSD.

From the presented results the following hints on parameter selection and results can be obtained:

- DSM GSD = 5 times image GSD,
- height accuracy approximately 2 times image GSD.

The quality certainly depends on the image texture, the image scale, the image overlap and on the parameter settings involved. If more image combinations are to be included, the processing time will increase, however, this can be justified by the higher quality of the derived surface model. One drawback can be encountered due to matching images across strips: the shadows in the image pairs across strips give rise to floating shadows due to the long time difference. This results in floating point clouds describing a non-existing surface. Similar effects can appear with moving objects.

3. DSM AND DTM GENERATION

The new MATCH-T DSM 5.2 (Beta) version (Inpho, 2009) has been applied to a rather very difficult area, an open pit mining of brown coal. The pit mine is flown regularly to derive DEMs about each month and to produce difference DEMs for volume calculations. The DEMs are derived by stereo measurements of morphological information and spot heights using digital photogrammetric workstations. The image data, the AT and reference DTM data has been provided by MIBRAG mbH, Germany, one of the major producers of brown coal and energy in Germany. Aerial triangulation was done by experienced MIBRAG's operators with very high accuracy for all data sets: sigma naught of about 0.2 pixels which corresponds to 2.1 µm and RMS values at check points of 0.04m to 0.05m in planimetry and 0.09m in height.
In an investigation by Zheltukina (2009) the impact of the new MATCH-T DSM and the used digital aerial camera DMC is investigated. An earlier investigation with a previous version of MATCH-T and a film camera showed problems in automatic DTM generation in steep and shadowed areas with interpolation oscillations, and in combination of models of the former model-by-model based approach. Table 2 shows the essential differences in flight parameters and MATCH-T versions.

Table 2: Differences between 2003 and 2008 in various flight parameters and MATCH-T versions.

	2003	2008
	Film Camera + Scanner	Filmless digital camera (DMC)
Pixel size & radiometric res.	21µm, 8 bit	12µm, 8 (12) bit
Spectral resolution	Black and white	RGB
Derived height models	DTM	DTM, DSM, Irregular point cloud
Matching technique	Model-by-model (MATCH-T 4.0)	Multi-image matching (MATCH-T DSM 5.2 (Beta)

Four "standard" data sets (June-September, 2008) are tested. "Standard" means the regular flown coverage of the area with aerial images at an image scale of 1:10000, 60% forward and 23% side overlap. Also two "Special" data sets (October-November, 2008) are used to investigate how an increase of the overlap (80% forward and 62% side overlap) influences the results for multi-image matching used in Match-T DSM 5.2. All images were taken with a DMC camera from a flying height 1200m above ground resulting in a pixel size of about 0.12m on the ground. The investigation was focusing on problematic areas as identified in the earlier investigation.

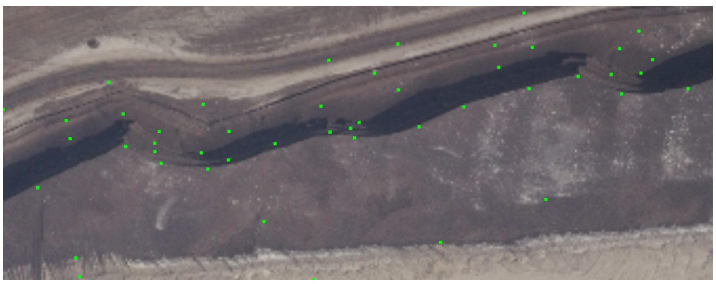


Fig. 3: Orthophoto of one test area of a steep shadowed slope. The marked check points have been measured manually in stereo mode (Zheltukina, 2009).

The accuracy of automatically derived DEMs and the provided reference data is first compared to 40 manually measured check points (cf. Fig. 3) in this selected area. The grid density is chosen at about a factor 3-4 higher (15cm) than usually. The results of the June 2008 test flight indicate, that for a DTM the strategy “DTM extreme” performs best, whereas for a DSM the “DSM undulating” setting as well as the chosen customized version of parameters perform best. The RMS values can reach about 0.2m accuracy. NoP is the number of points for which the deviation from the DEM exceeds the user-defined tolerance, it is rather low in the DSM cases. The quality of the DTM derived from MIBRAG reference data is not representative in this case, as the generalization of break-lines was rather strong at the examined slope areas.

Table 3: Some statistical results (RMS, Max, Min and NoP) of different parameter settings of June 2008 test flight in comparison to manually measured check points. NoP is the number of points exceeding the tolerance.

General Information	Generating Strategy	RMS [m]	Max [m]	Min [m]	NoP
June, 2008 40 control points grid 0,15m tolerance = 0,3m	MIBRAG DTM	0,945	3,480	-0,826	21
	dTm_extreme	0,286	0,741	-0,717	9
	dTm_customized	0,342	0,931	-0,972	13
	dSm_undulating	0,213	0,530	-0,615	4
	dSm_customized	0,192	0,682	-0,531	2

For each data set the grid size is then varied. It was found out, that the “DTM extreme” strategy with 1.8m grid size (about 15xGSD) and the “DSM undulating” strategy with 0.45m grid size (about 4xGSD) gave overall the best results. These two strategies with the selected grid sizes are then applied to the whole open pit mine test area to be compared with manually measured check points (Zheltukhina, 2009).

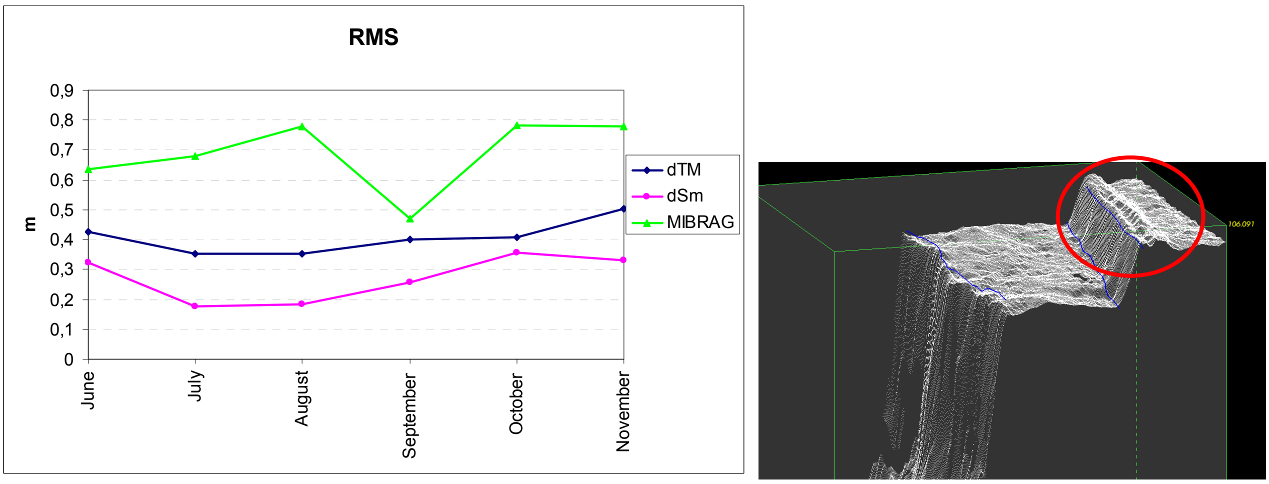
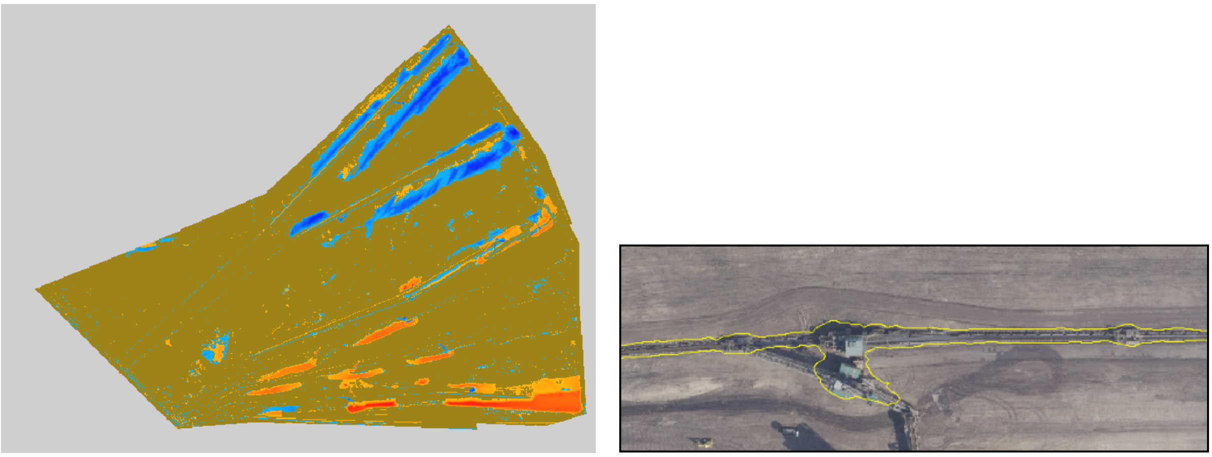


Fig. 4: a) Graphical representation of the RMS of derived DEMs as compared to manually measured check points (accuracy about 0.12m). The number of check points varied from 1988 to 3036 due to the ongoing filling and cutting during the months. b) Automatically matched points describe in this case the surface more precisely and more detailed than the reference data (manual break-lines in blue).

The RMS values for the automatically measured DTMs are in the range of 0.4-0.5m, the RMS values for DSMs are in the range of 0.2-0.3m (cf. Fig. 4a). The derived DTM from MIBRAG data shows in the examined cased higher values, due to generalization effects observed especially at steep slopes. The accuracy values of 0.4m for DTMs and 0.3m for DSMs are used as thresholds for the detection of significant changes (section 4). This quality of the derived DTMs and DSMs is comparable to the manually measurements of the production process. The automatically derived DSMs are partly even more detailed than the provided reference data (cf. Fig. 4b). In this investigation the examined DSM parameters show slightly better performance than the DTM parameters. The customization of parameter sets does not really bring an advantage, thus default parameter settings for this type of terrain could be applied. A higher redundancy compared to earlier MATCH-T versions is reached by the sequential multi-image matching and can be further increased by applying the full 12 bit information (Heuchel, 2005).

4. CHANGE DETECTION IN OPEN PIT MINING

Having found the optimal set of parameters and having information on the quality of the derived Digital Elevation Models (DEMs) as described above, the next task is to detect significant changes to derive a volume estimate of cutting and filling areas. The difference DEMs are calculated by SCOP++ (Inpho, 2009) and the quality of the automatically derived are taken into account. The add-on SCOP Poly of inpho GmbH is used to assist in detecting changes in difference DEMs. It generates polygons around areas with heights in user defined intervals. For the difference DSM as shown in Fig. 5 the height threshold of ±0.3m is used. In addition a minimal area threshold of $4500m^2$ is applied. The areas in green are in an interval (-0.3m; 0.3m) and are considered to be unchanged as it is not possible to separate the changes from noise in this interval of heights. The areas with heights in difference model less than (-0,3m) correspond to the areas of filling and more than 0.3m to the areas of cutting.



a) b)

Fig. 5: a) Difference model (Oct-Nov) from automatically generated DSMs. Unchanged areas (-0.3m and +0.3m) are shown in green. Filling areas are shown in blue, cutting areas are shown in red. b) One automatically derived polygon of change. It indicates one of the huge machines working in the area.

The final volume determination yields very promising results. In the case of the October-November difference DSM the values for filling differed only by 0.2% and for cutting only by 1.2% from the difference DTM produced by MIBRAG mbH (cf. Table 4). The MIBRAG result was based on manual measurements of two DTMs. For the automatically derived MATCH-T DSMs only a final manual deletion of five polygons indicating single machines was applied. Results still contain some machines or machine parts moving during and between flights, they are so far not taken care of.

Table 4: Computed volume of changes with a ±0.3m height threshold for DSM (Oct.-Nov. 2008). In the case of the HFT DSMs five automatically derive polygons indicating single huge machines were manually deleted.

Period & DEM type	Type of change	MIBRAG DTMs Manual Volume [m^3]	HFT DSMs Automatic Volume [m^3]	Difference MIBRAG-HFT Volume [m^3]	Difference in % of MIBRAG Volume [%]
10-11 DSM	filling	4296235,50	4287573,17	8662,33	0,20
	cutting	5198767,17	5135588,81	63178,36	1,22

5. BUILDING EXTRACTION

The high quality and density of point clouds from image matching opens new potentials for building extraction in urban areas. The software Building Generator is applied to point clouds from MATCH-T DSM as well as from LIDAR data.

5.1. Building Generator

Inpho´s software Building Generator allows the derivation of LoD (Level-of-Detail) 1 or LoD 2 buildings (according to OGC City GML standard) from dense 3D point clouds and given building ground-plan information. The objective is to produce 3D building models for large areas. The basic three steps (Fig. 6) are 'Ground plan generalization' with a division into Rectangle-, L-, T-, U- and complex shape. A 'Segmentation' step adjusts planar segments to surface points inside a ground plan polygon. The 'modeling' allows the derivation of predefined basic volumetric primitives in LoD 2 (Fig. 7), i.e. with roof structures or if not possible or applicable of a LoD 1 representation, with only one building height. The evaluation of parameter settings and influence factors as well as a comparison to the performance with LIDAR point clouds is given in Grau (2008). Very complex building shapes require a subdivision of the 2D ground plans as shown in Fig. 8.

Given 3D point cloud and ground plan data

Ground plan generalization
Analysis of given ground plan structure Division into : Rectangle-, L-, T-, U-, and complex shape

Segmentation
Surface points in a ground plan polygon
Adjustment of points to planar segments

Modelling
LoD 2 (basic primitives) or LoD 1

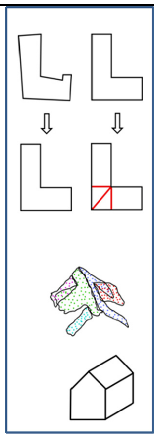


Fig. 6: Building Generator applies three basic steps to derive building models in LoD 2 or LoD 1 based on a given 3D point cloud from LIDAR or MATCH-T DSM and given building ground plans.

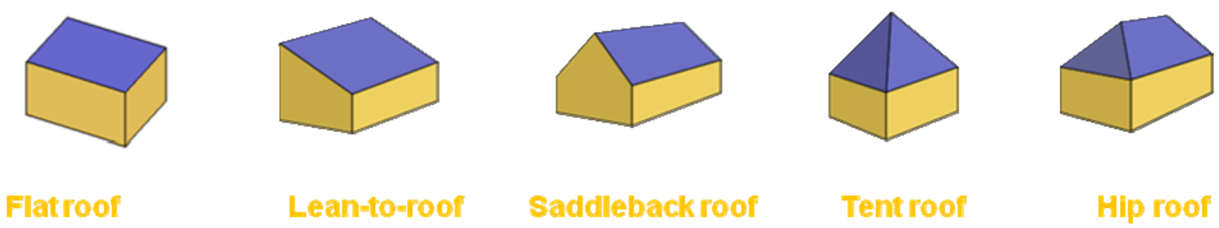


Fig. 7: Basic primitives as building models for LoD 2 in Building Generator.

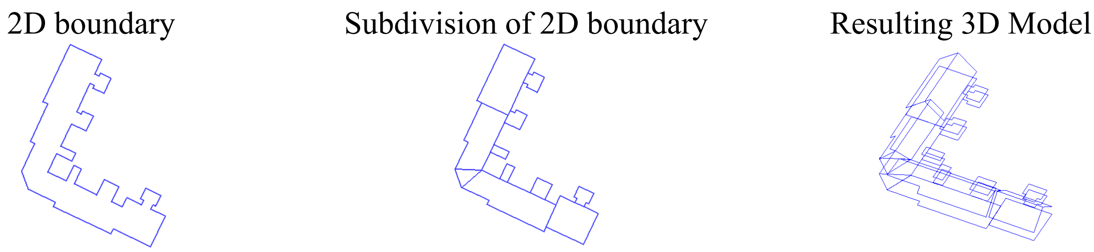


Fig. 8: Example for subdivision of 2D boundaries and resulting 3D models.

5.2. Test data

Three test areas (Fig. 9) have been selected, the data being provided by inpho GmbH and some of their business partners. In one data set (Bautzen) LIDAR and MATCH-T DSM data are available.

Graz
High density, complex roof types and ground plans

Toulouse
Sparse, single houses with simple structures

Bautzen
High density, complex roof types and ground plans

Fig. 9: Examples of aerial image patches of the three chosen test areas and characteristic features.

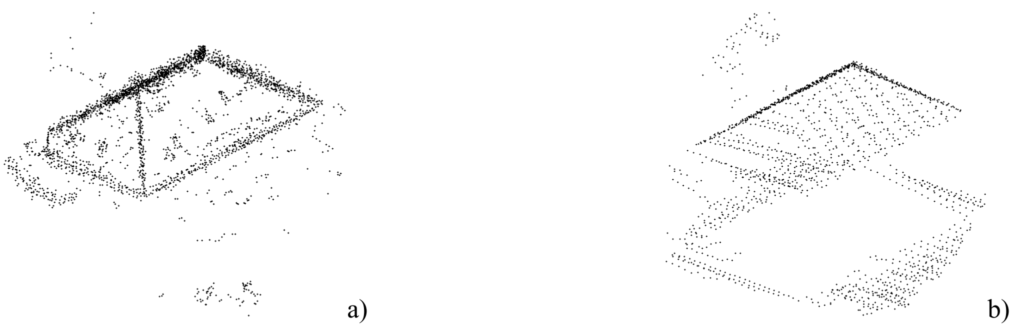


Fig. 10: Structure of point clouds differs between a) MATCH-T and b) LIDAR data.

The structure of the point cloud differs quite a lot between MATCH-T and LIDAR, as shown in Fig. 10a) and b). The MATCH-T DSM point cloud does not show the same type of regularities, but it has a quite dense point distribution along the roof edges. Also the density and the quality of height values (Table 5) have an impact on the final building extraction. The point density in MATCH-T DSM is usually very high, but as Fig. 10a indicates, this is not an average point density as in the case of LIDAR and should be regarded only as an approximation. The SDEV in height in case of Bautzen data set is by a factor of 3-4 better in the case of the LIDAR point cloud, but similar like in Toulouse data set.

Table 5: Point cloud density and height quality (given as standard deviation SDEV) in the test data sets.

Test area	Graz	Toulouse	Bautzen	
Point cloud	MATCH-T DSM	MATCH-T DSM	LIDAR	MATCH-T DSM
SDEV in height [m]	0.20	0.09	0.06	0.22
Point density (points/m²)	76	11	5	11

Table 6: Manually measured ground plans and distribution of shape types in all test data sets.

	Shape type				
Test data set	Rectangle	Complex	L	T	U
Graz (MATCH-T DSM)	39	9	28	9	17
Toulouse (MATCH-T DSM)	92	12	19	5	2
Bautzen (LIDAR)	59	7	28	5	3
Bautzen (MATCH-T DSM)	39	5	20	2	2

As for the test data sets ground plan data have not been available 334 building ground plans are measured manually (cf. Table 6). This allowed introducing different shape type of buildings in a controlled way to check the quality of building extraction depending on those shapes.

5.3. Results

The first investigations concern the parameter settings. It is found, that for the segmentation steps essentially only very few parameters are important which makes the software really suitable for real world applications. Among those are the parameters 'NNCount', 'Point Sigma', 'Point-to-plane threshold' and 'Plane-to-plane threshold'. However, the value selection for those parameters requires knowledge on the structure of the point cloud, i.e. it must e.g. be known is the point cloud derived from image matching or from LIDAR. The parameters for the generalization step are not very sensitive to parameter changes. The software, however, requests a subdivision of very complex shapes to yield good results which was in this test only possible to do manually. The complexity of the building is definitely decisive for the parameter selection. Based on extended empirical investigations with 40 different parameter combinations the following results could be obtained:

Table 7 : Success rate of building extraction in the test areas for building shapes. The median value in % of LoD 2 modeling for all investigated parameter combinations is shown as well as the average extraction time.

Test Area	Graz	Toulouse	Bautzen	
Point cloud	MATCH-T DSM	MATCH-T DSM	LIDAR	MATCH-T DSM
Rectangle shape	66,7 %	95,7 %	76,3 %	60,3 %
L-shape	25,0 %	94,7 %	42,9 %	27,5 %
T-shape	77,8 %	100,0 %	60,0 %	50,0 %
U-shape	17,7 %	100,0 %	33,3 %	25,0 %
Complex shape	11,1 %	66,7 %	28,6 %	20,0 %
Time/Building [sec]	44,45	2,20	1,96	4,41

The success rate for Rectangle shape buildings is generally much higher than L-, T- or U-shape buildings. The Toulouse data set shows best performance with a sparse distribution and simple building structures. In case of complex ground plans only very seldom LoD 2 level building models can be reached. The success rate in case of Bautzen is on an almost similar level than from the LIDAR point cloud. However, the other data sets show, that quite high success rates can be reached. The parameter selection can in all those examples be reduced to a very low number of decisive ones. Still further improvement is requested. The most critical cases are the complex shapes which require a sub-division of the ground plan. The time needed to extract a building can be from 2 seconds to more than 40 seconds for highly complex buildings. However, this should be not over estimated, as it is an automated procedure, without human interaction during the process.

5.4. Point Cloud Classificatio with Image Support

Further improvements can be reached by using the image support for point cloud classification. In Djaba (2009) it is shown on some examples, that a simple NDVI classification using RGB and NIR channels and advanced filtering methods adapted from LIDAR point cloud filtering allow to derive the four different classes from dense MATCH-T DSM point clouds: ground vegetation, ground non-vegetation, off ground vegetation, and off ground non-vegetation. This allows to introduce context information in the building extraction and to reduce the amount of gross matching errors or at least to indicate vegetation areas, where image matching has by nature difficulties.

6. CONCLUSIONS

The results of the presented investigations show, that a very high level of automation can be reached by exploiting filmless digital cameras and the new MATCH-T DSM. The DEMs in the open pit mining area are generated completely automatically without collection of morphological data. The results are accurate enough compared to the standard workflow with human stereo measurements. The automatic volume determination shows in average only 0.2-1.0% difference to the manually derived volumes. The software Building Generator is evaluated for building extraction using given 2D ground plans of buildings and MATCH-T DSM point clouds in urban areas of different complexity and density. Extensive empirical investigations of parameter settings show, that there are only few decisive parameter settings needed for promising results. In areas with simple to moderate complexity building types standard shaped buildings can be reconstructed in LoD 2 with up to more than 95% success rate. If the extraction in LoD 2 (Level-of-Detail) fails, a LoD 1 model is derived. The success rates can come close to those using LIDAR point clouds. In case of complex buildings and high density of buildings the success rates are partly much lower with strong dependencies on the subdivision of the given 2D ground plans. This requires further research and development. First investigations on point cloud classification using image support and remote sensing classification techniques indicate the potential to improve the building generation from point clouds further.

7. ACKNOWLEDEGEMENTS

The support by MIBRAG mbH, Germany in providing image and reference data for the change detection investigations is gratefully acknowledged. Many thanks to inpho GmbH for providing access to the MATCH-T DSM 5.2, to SCOP Poly, to Building Generator and example data for the building extraction investigations from different partners. Many thanks to MSc. Natalia Zheltukina, MSc. Herbert Djaba and to Dipl.-Ing. Stephan Grau for carrying out the empirical investigations.

8. REFERENCES

Djaba, H. K. (2009): MATCH-T DSM Point Cloud Classification Using Aerial Image Support. Master Thesis HFT Stuttgart.

Grau, S. (2008): Untersuchungen und Vergleiche zur Gebäudemodellierung mit Match-T DSM- und LiDAR-Daten. Diploma Thesis HFT Stuttgart.

Gülch, E., Müller, H., Hahn, M. (2004): Semi-automatic object extraction – lessons learned. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXV.

Haala, N., Wolff, K. (2009): Digitale photogrammetrische Luftbildkamerasysteme – Evaluation der automatischen Generierung von Höhenmodellen. Tagungsband 18/2009, Jahrestagung DGPF Jena, Germany.

Heuchel, T. (2005): Experience in Applying Matching Techniques Using Images from Digital Cameras. 'Photogrammetric Week 05', Heidelberg, Germany.

Inpho (2009): inpho GmbH. http://www.inpho.de

Lemaire, C. (2008): Aspects of the DSM production with high resolution images. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVII, Part B4, pp. 1143-1146.

Lothhammer, K.-H. (2008): Aspects of DSM production. Proceedings of Map Asia 2008, Kuala Lumpur, Malaysia.

Zheltukhina, N. (2009): Change detection in open mining pit using digital cameras and image matching. Master Thesis HFT Stuttgart.